Principal Geological Aspects of the Chilean Fjord Region

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General Introduction

South of Puerto Montt the western part of Chilean territory fragments into a maze of islands that extends down to the end of the continent (Figs. 1&2). This unusual feature is the result of glacial erosion and the retreat of the ice caps during the Pleistocene. In that epoch, as a result of a global temperature decrease, a continental ice cap covered a large part of the southern tip of South America, reaching the Pacific Ocean to the south of the Chiloé Archipelago and Cape Horn. The retreat of the continental ice caps occurred approximately 15,000 years ago, leaving the North and South Patagonian ice fields as present-day remnants. This unique fiordic environment was established by the retreat of the continental ice cap; the glacier-carved valleys were filled by the rising sea-level. Thus, the Chilean Fjord Region reflects very young geological processes compared to, for example, the Atacama Desert in the North of Chile, which has survived under essentially constant conditions for millions of years.

In the fjord region important aspects of the morphology, and therefore the moulding of the presently-observed landscape, stem from the action of the ice. This origin has determined the main characteristics of the exposed land: steep topography; the existence of clean, fresh rock exposures along the long coastline of the islands and the border of the continental territory; incipient development of soil; and a few localized Holocene deposits — some of the latter related to volcanic activity.

The dense forest coverage of the majority of the region makes geological observations difficult, confining the best rock exposures to the intertidal zones, coastal cliffs and high mountain regions. Studying the exposed rocks in the archipelagos of south-central Chile allows deciphering of the geological history of this region, one which extends over 500 million years from the Paleozoic epoch to the Holocene (see Fig. 3).

Summarized in the following text are the principal geological characteristics of the regions of Chiloé, Aisén and Magallanes, as well as the principal aspects of their geological and tectonic evolution. The easternmost regions of the Patagonian Cordillera will be mentioned only in a comparative sense. The text considers the most modern and comprehensive references, whereas the older and more geologically detailed documents, which include geological maps of the area dealt within the present text, are cited in the "Recommended Bibliography". For more details and an extended bibliography, see App. 4 on www.huinay.cl.

Present Tectonic Setting (Fig. 1)

The Andes of south-central Chile (Fig. 1) represent an active orogen, associated with the eastward subduction of the Pacific oceanic lithosphere, represented by the Nazca and Antarctic plates, beneath the margin of the continental South American plate (Dewey & Bird, 1970; Mpodozis & Ramos, 1989). An important characteristic is the presence near the Taitao Peninsula of the Chile Triple Junction, where the Nazca, Antarctic and South American plates meet (Fig. 1). The locus of this junction has been moving northwards along the continental margin since the Miocene (15 Ma ago, see Fig. 3) when the Chile Rise, which separates the Nazca and Antarctic plates, impinged upon the southern extremity of the continental margin.

Spatially related to the Chile Triple Junction, the Liquiñe–Ofqui Fault Zone (LOFZ) is developed north of the Golfo de Penas basin (Fig. 1). The LOFZ is an active, intra-arc, dextral, strike-slip mega-fault, that extends for more than 1,000 km along the Andes, favouring the location of numerous volcanic edifices along its main trace and associated branches. Glacial erosion has resulted in straight or slightly curved valleys and fjords that have developed along this structure, which also exerted an important control on the previous geological characteristics of the region. It is interesting to note that in the segment of the Patagonian Andes where the

LOFZ is present a Longitudinal (or Central) Valley has developed, the floor of which is submerged south of Puerto Montt along the Moraleda channel. However, no such topographical feature (Central Valley) exists south of the Golfo de Penas, where there is no tectonic fault equivalent to the LOFZ.

The region north of the Golfo de Penas was affected by the great 1960 Valdivia earthquake, which produced coastal uplift and subsidence as well as numerous landslides along the main trace and branches of the LOFZ. The rate of Andean uplift has been estimated for the area of continental Chiloé (Ota & Hervé, 1993) as reaching more than 10 m/ka in the vicinity of the LOFZ. More recently, the seismic swarm of the Aisén Fjord in 2007, the associated landslides and tsunami, as well as the eruption of the Chaíten volcano in 2008, were controlled by activity on the principal fault and one of its branches, respectively.

The archipelagos of southern Chile encompass the morphostructural units of the Patagonian Andes, the Fuegian Andes and the Magallanes Basin (Fig. 1), each of which has distinctive lithotectonic associations and its own geological evolution.

The Patagonian Andes consist principally of the Patagonian Cordillera but also include the Central Valley and the Coastal Cordillera. The Patagonian Cordillera is formed, essentially, by Cretaceous-Miocene granitoids that constitute the Patagonian Batholith. Blocks of Paleozoic metamorphic rocks appear within and on both sides of the batholith, along with scarce outcrops of Jurassic-Cretaceous volcanic and sedimentary rocks. These occur more extensively exposed and generally less deformed on the eastern side of the Patagonian Andes. The Patagonian Cordillera is crowned by active volcanoes of the Southern Volcanic Zone of the Andes, which was established in Pleistocene-Holocene times. This zone extends as far as 46°S, but with many fewer volcanoes in the Magallan region. The Central Valley, largely covered by Pleistocene deposits, is below sea level south of Puerto Montt, but Oligocene-Pliocene volcanic and sedimentary remnants appear at its eastern and western borders. The Coastal Cordillera is seen in the western part of the Chiloé Archipelago and in the Chonos Archipelago. This was principally formed by Paleozoic-Triassic and Triassic-Jurassic metamorphic rocks, with a limited presence of Mesozoic-Cenozoic intrusive rocks.

To the south of the Golfo de Penas the Patagonian Cordillera passes progressively into the Fuegian Andes, whose most distinctive feature is the occurrence of ophiolitic complexes, a result of the rupture of the continental crust during Jurassic-Early Cretaceous times, generating a marginal basin of “green rocks”.

Towards the east of the Patagonian and Fuegian ranges a mid-Cretaceous basin was formed known as the Magallan foreland basin, a major hydrocarbon producer, which was filled by several thousand metres of marine and continental sedimentary rocks, subsequently to be deformed during the Late Cenozoic.

Relationships between Geology and Local Geomorphology in the Coastal Outcrops

Introduction

Geological work in the fjord region is done principally from the sea. At each outcrop visited, the geologists have to choose where to disembark, which is often technically difficult but unavoidable. Among the difficulties, the main question is that of wind and wave conditions. The the local geomorphological characteristics of coastal outcrops are problematic. These characteristics depend essentially on the type of rock present, on the evolutionary processes that affected them, and on their exposure to the erosive action of the waves. The morphology of the coastal outcrops and the composition of the rocks undoubtedly influence the type of biota found. Although a systematic study of this relationship has not been undertaken, general aspects of the dominant local morphology in the different types of rock along the coasts of the Chilean Fjord Region are presented below.

General Description

The coastline of the Chilean Fjord Region illustrates the erosive action of the glaciers that covered the area during the last glacial period. This is demonstrated in the pattern of the coastline, dominated by long and often intricate fjords, and in details of the coastal rock outcrops, where the rounded forms of “roches moutonnées” are very frequently seen, associated with surfaces exhibiting glacial striations. The long-term preservation of these

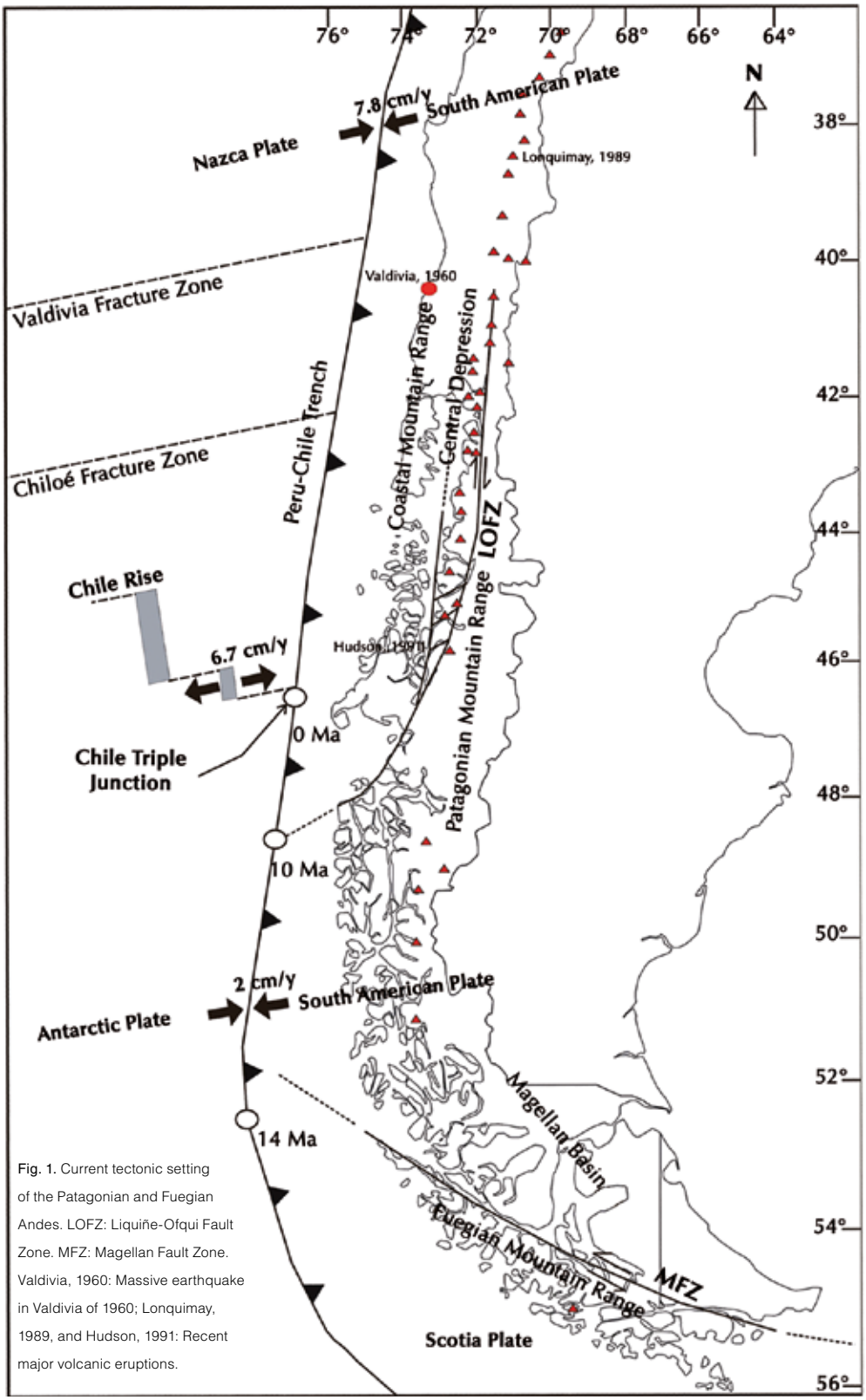

Fig. 1. Current tectonic setting of the Patagonian and Fuegian Andes. LOFZ: Liquiñe-Ofqui Fault Zone. MFZ: Magellan Fault Zone. Valdivia, 1960: Massive earthquake in Valdivia of 1960; Lonquimay, 1989, and Hudson, 1991: Recent major volcanic eruptions.

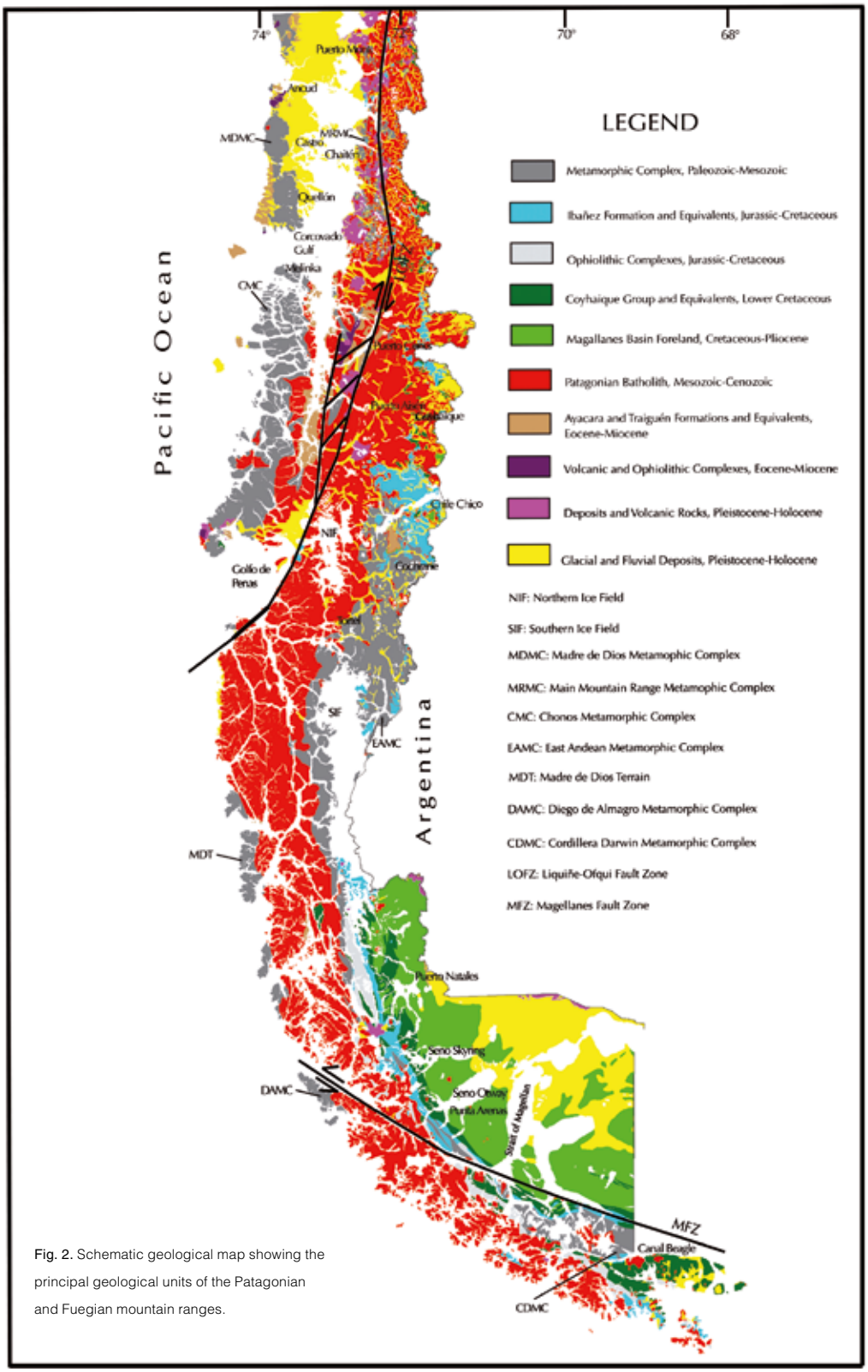

Fig. 2. Schematic geological map showing the principal geological units of the Patagonian and Fuegian mountain ranges.